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Playas (dried lakes), commonly formed in arid basins, can have surface conditions ranging from hard and dry to soft and moist. These surfaces result from the relation between the hydrologic environment and the mineralogy of the surrounding basin. Surfaces composed of soluble salts deposited by capillary action from saline ground water can be found on playas in structurally closed basins. In order to determine methods of discriminating different saline mineral deposits using multispectral imagery, spectral reflectance data (400 to 2500 nanometer (nm) range) of selected saline playas in the Mojave Desert were collected using a portable spectroradiometer. The reflectance data included field spectra of salt crusts and laboratory spectra of pure compounds and salt mixtures.

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SPECTRAL CHARACTERISTICS OF SOME SALINE PLAYA SURFACES AND THEIR APPLICATION TO MULTISPECTRAL IMAGERY ANALYSIS

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ABSTRACT

Playas (dried lakes), commonly formed in arid basins, can have surface conditions ranging from hard and dry to soft and moist. These surfaces result from the relation between the hydrologic environment and the mineralogy of the surrounding basin. Surfaces composed of soluble salts deposited by capillary action from saline ground water can be found on playas in structurally closed basins. In order to determine methods of discriminating different saline mineral deposits using multispectral imagery, spectral reflectance data (400 to 2500 nanometer (nm) range) of selected saline playas in the Mojave Desert were collected using a portable spectroradiometer. The reflectance data included field spectra of salt crusts and laboratory spectra of pure compounds and salt mixtures. Results show that while certain common soluble materials such as potassium chloride and sodium chloride are spectrally featureless in the Landsat Thematic Mapper (TM) visible and near infrared bands, others such as calcium sulfate and calcium chloride have absorptions in TM bands 5 and 7 which allow their discrimination from other salts. Knowledge of the spectral characteristics of these materials allows the selection of band combinations and ratios which maximize the discrimination of different surfaces using TM multispectral imagery.

INTRODUCTION

The term playa, in the geologic sense, is applied to the flat central area of a desert lake basin. The military interest in playas stems from experienced and perceived problems of mobility, dust production and water supply exploitation. Playas are found in arid basins worldwide and the ability to detect and determine surface conditions would be useful for terrain analysis and planning for desert operations. Playa surfaces can vary greatly between individual basins and by no means are all dry lakes flat, hard, surfaces capable of supporting vehicle traffic or aircraft operations. Considerable work has been done in trying to interpret playa surface composition and conditions in various field, laboratory and remote sensing studies by the U.S. Air Force, the U.S. Army and the U.S. Geological Survey (Henley 1988; Stevens 1988). Some recent European studies have shown the use of Thematic Mapper for monitoring playa hydrologic dynamics (Millington et al. 1989). This paper will address one type of playa and the potential of using multispectral data to make assessments of the surface materials and conditions.

Saline playas

Important factors determining playa surface type are the hydrologic environment and the mineralogic character of the basin. The hydrologic characteristics are influenced by the physical structure of the basin which determines the movement of surface and ground water into and out of the valley (Snyder 1962). If the valley is structurally open to subsurface flow, ground water moves out and the water table will be relatively deep and the playa surface will be controlled by run-on water which evaporates quickly. These playas will be nonsaline with smooth, hard surfaces which are dry in the dry season. But if the valley is structurally closed with no outlet for ground water, the water table will likely be high or near the surface, resulting in substantial capillary rise and a wet surface during the dry season. The mineralogy of the surrounding basin will influence the chemical nature of ground water and in a closed basin the chemical concentrations will increase over time which can result in highy saline brines and deposition of salts at the surface by capillarity. Large deposits of soluble minerals may be present in some playas resulting from deposition and concentration in former pluvial lakes during the Pleistocene and the present input to the systems may be minor. The deposition and crystallization of salts within the surface sediments will produce a very soft, loose hummocky surface which has been called "self-rising ground" (Neal 1972). Some large playas such as in Death Valley can be compared to large evaporation pans and the different salts are deposited in sequence reflecting their solubility (Hunt 1966). The least soluble materials, carbonates of calcium and magnesium, are the first deposited; the most soluble, the chlorides, are the last with the sulfates in between. This results in a zonation of salts vertically and horizonally within the playa. Some of the saline playas are sites of commercial extraction of salts by various methods from the subsurface brine.

PROCEDURES

In order to determine methods of discriminating different saline mineral deposits using multispectral imagery, spectral reflectance data (400 nm to 2500 nm range) were collected from surfaces on selected playas in the Mojave Desert. A Geophysical Environmental Research (GER) IRIS MK IV Spectroradiometer was used for spectral data collection. Measurements were made on <u>in situ</u> playa surfaces using solar illumination and on pure salts and salt mixtures in the laboratory using tungsten-halogen illumination. All measurements were made with the viewing angle normal to the target surface and calculated as percent reflectance of a simultaneously recorded Halon reflectance standard. Reflectance spectra collected in the lab were nearly identical to field spectra in both shape and amplitude of the traces. The lab spectra did not, however, suffer from noise caused by the atmospheric water absorptions bands centered near 1400 nm and 1800 nm which is seen in field collected spectra. Average reflectance values were calculated for each TM band from the high-spectral resolution field data. These data were compared to Landsat Thematic Mapper data (scene ID E-51147-17390, April 1987).

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The TM digital numbers were converted to radiance values using NASA supplied calibration coefficients (Barker and Markham 1986). By using the field measured percent reflectance of selected playa surfaces in each TM band and the TM radiance value of these surfaces, a maximun TM surface radiance, i.e., the radiance value which would result in 100 percent reflectance, was calculated for each band. The radiance value image was converted to a percent reflectance image by the equation: Band Refl. = (Band Rad./Band Rad. max) * 100. There was no atmospheric correction. The resulting reflectance values for each pixel are not identical to the ground level measurements but the interband reflectance relations are very similar (see Table 1).

RESULTS

Danby Playa and Bristol Lake were selected for this study. Both are located in the eastern Mojave Desert west of the Colorado River (Needles 1:250,000 map sheet NI-11-6). Both playas contain commercial extraction facilities for soluble salts. The extraction at Danby Playa is by sinking shallow wells into the subsurface brine and pumping this into shallow ponds for evaporation. The salt extracted here is sodium chloride. There are also large surface and shallow subsurface deposits of selenite gypsum at Danby.

Bristol Lake, occupying the next basin westward from Danby, has extensive commercial extraction facilities. Here, the method of extraction is to dig long trenches into which shallow saline ground water flows and evaporates. The salts extracted here are sodium chloride and calcium chloride with the CaCl being the primary commercial product.

Laboratory reflectance spectra of soluble salts commonly found on saline playa surfaces are shown in Figures 1-4. These samples are reagent grade materials and do not contain impurities, nor are they mixtures of sediments as would be found on natural playa surfaces. The gypsum sample is a pure selenite gypsum sand from White Sands National Monument, New Mexico. Most salts are spectrally flat except for water and hydroxyl absorptions (Hunt and Salibury 1972). Major free water absorptions are centered at 1400 nm and 1900 nm. Most soluble salts are hygroscopic and are in nature never truly dry. Free water can also occur as inclusions in the salt surfaces. Minerals such as gypsum also have water as part of the crystal lattice which cannot be removed without destroying the mineral structure. The laboratory spectra show that gypsum and calcium chloride have major absorptions in the 1400 nm and 1900 nm water absorption bands and some minor features centered at 1000 nm and 1200 nm. The reflectance characteristics of these materials in the regions covered by the TM bands are similar. The reflectance of NaCl and KCl is generally flat throughout the visible and near-infrared spectra with absorptions only in the water bands at 1400 nm and 1900 nm. These salts are highly reflective in all the TM spectral bands.

The reflectance spectra collected on *in situ* playa surfaces are shown in Figures 5-7. The effect of atmospheric water absorption is seen in the noisy regions at 1400 nm and 1800

nm. Moisture greatly affects the reflectance of any material in the 1550 nm to 1750 nm (TM band 5) and 2080 nm to 2350 nm (TM band 7) regions of the spectrum. Increasing moisture will decrease the reflectance and total extinction or absorption will occur with a depth of a few centimeters of standing clear water. Figure 5 shows the reflectance of a thick, white, dry sodium chloride deposit in an abandoned salt evaporation pond on Danby Playa. This surface has very high reflectance throughout the visible and near-infrared spectrum. The effect of moisture on this same type of material is seen in Figure 6 which is a wet sodium chloride surface in an active evaporation pond. This material is moist but there is no standing water on the surface. The reflectance is still high in the visible and near infrared region covered by TM bands 1 through 4, but the presence of water has greatly decreased reflectance in the TM bands 5 and 7 region. By comparing these TM band reflectance of the different soluble salts it is seen that wet NaCl and CaCl could not be separated spectrally.

Table 1. Field measured and image-derived reflectance values in the TM bands for some saline surfaces on Danby Playa and Bristol Lake. Values are percent reflectance.

Surface	TM1	TM2	TM3	TM4	TM5	TM7
(Danby Playa)	(Ground measured/derived image)					
Wet NaCl	55/48	63/58	65/65	68/70	22/35	11/11
Dry NaCl	48/48	54/58	58/65	62/67	65/65	63/55
Brine	*/48	*/56	*/62	*/24	*/5	*/0
Gypsum	35/48	41/42	50/57	55/55	54/65	40/44
(Bristol Lake)						
Wet NaCl	43/52	47/59	51/60	53/63	16/16	8/8
Wet CaCl	*/52	*/42	*/49	*/47	*/20	*/16
Clear water	*/30	*/18	*/18	*/15	*/10	*/8

* = not measured in field

Description of surfaces shown in table:

Danby Playa

Dry NaCl - Clean, white salt crust in abandoned evaporation pond. Surface and subsurface were dry.

Wet NaCl - White, wet salt surface in active evaporation pond. Surface was wet to the touch, but there was no standing water on the surface.

Brine - Surface of a recently filled evaporation pond. One to three inches of clear liquid over a white salt bottom. Reflectance of this surface was not measured in the field.

Gypsum - Weathered mounds of massive gypsum in the eastern part of the playa. Color was yellow-brown.

Bristol Lake

Wet NaCl - White salt crust on large pond on the western end of the lake. Surface was damp to the touch.

Wet CaCl - White surface of CaCl in an evaporation ditch. This surface could not be measured in the field.

Clear water - Clear ground water in a recently excavated ditch. This surface could not be measured in the field.

Band selection for discriminating some saline surfaces

Having a knowledge of the reflectance characteristics of surfaces shown on a multispectral image will help in selecting the bands in which there is sufficient spectral contrast to separate the different surface conditions. For saline playa surfaces, which are usually light-toned or highly reflective in the visible region, there is low contrast in TM bands 1 through 4. In a color composite image made from any of these bands, all of the white salt surfaces, wet or dry, would appear to be the same (white) if there was no standing water. The presence of water, either on a surface or as an integral part of a mineral's composition, has the effect of lowering the reflectance in TM bands 5 and 7. Therefore, selecting a band in the visible region and two infrared bands will give sufficient contrast to separate wet and dry salts. A band selection of TM bands 3, 4 and 7 is useful for discriminating between wet salt, dry salt and standing water. Using TM bands 3-4-7 assigned to red-blue-green to produce a color composite image will show the following color relations:

Dry NaCl surfaces will be white in color (high values on all color guns).

Wet NaCl surfaces will be bright yellow (high values on red and green, low value on blue).

Brine in ponds will be red-orange (high value on red, lower value on green and lowest on blue).

Gypsum surfaces will be a light yellow and could be confused with a moist NaCl.

Clear relatively deep water will be black (low values in all bands).

This band combination is also useful for separating green vegetation which will be seen as green (low on red, high on red and low on blue).

CONCLUSIONS

The interpretation of multispectral imagery is greatly enhanced if the spectral reflectance characteristics of the surface are known. Ground-level reflectance measurements can be used to adjust the brightness values in Thematic Mapper data to approximate reflectance values. Knowledge of the interband reflectance relations helps in band selection for discriminating various surface composition and moisture conditions.

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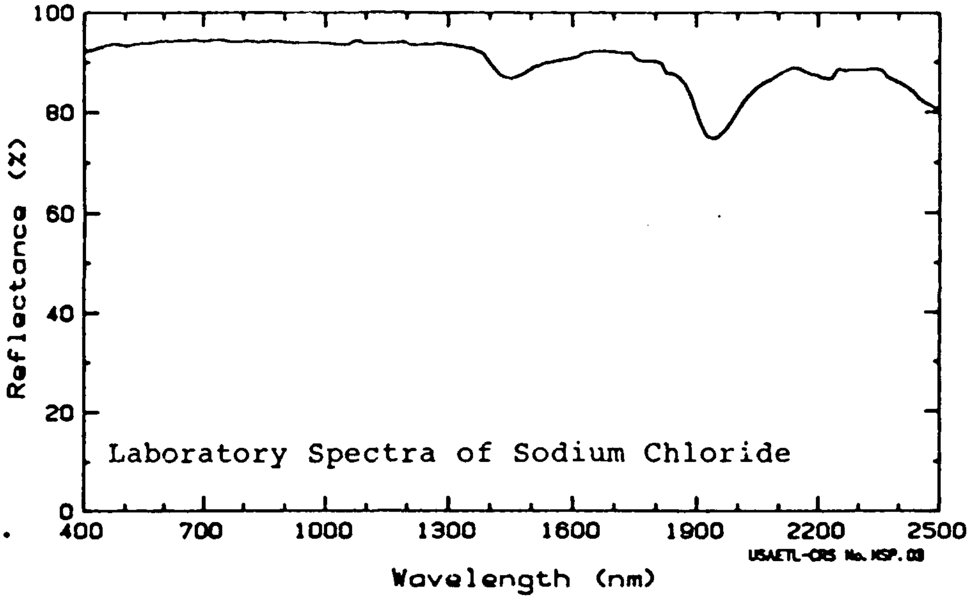

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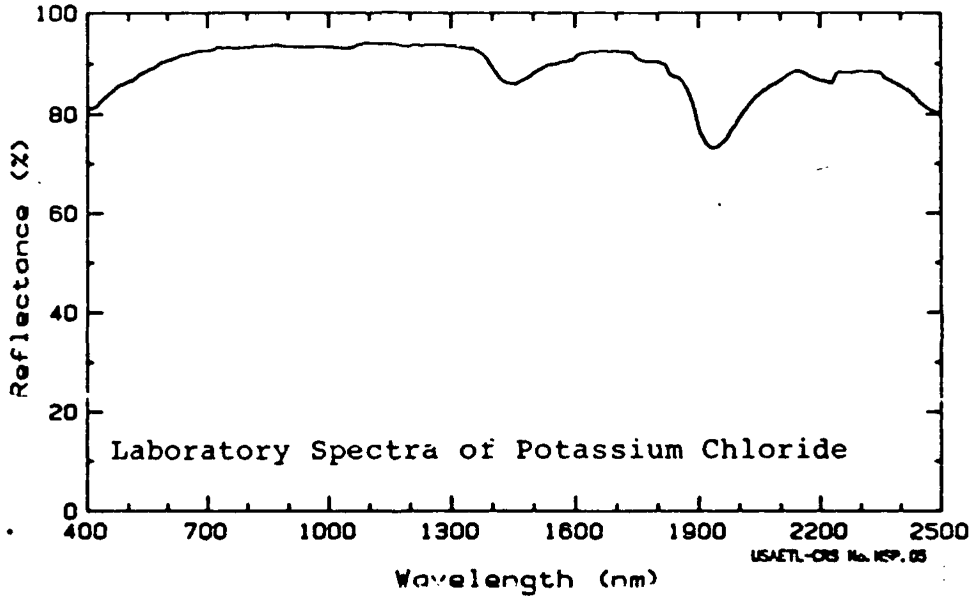

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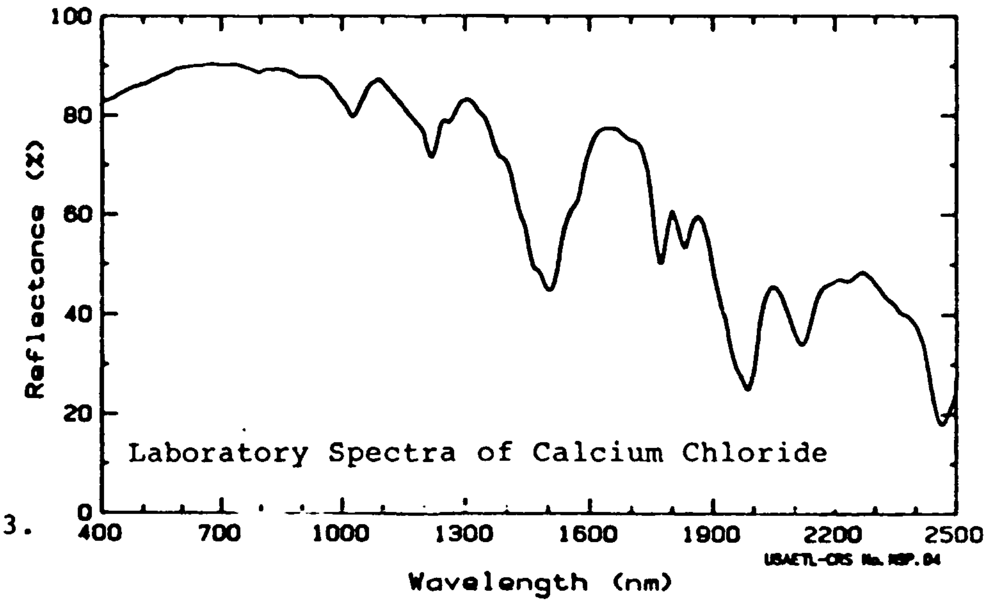

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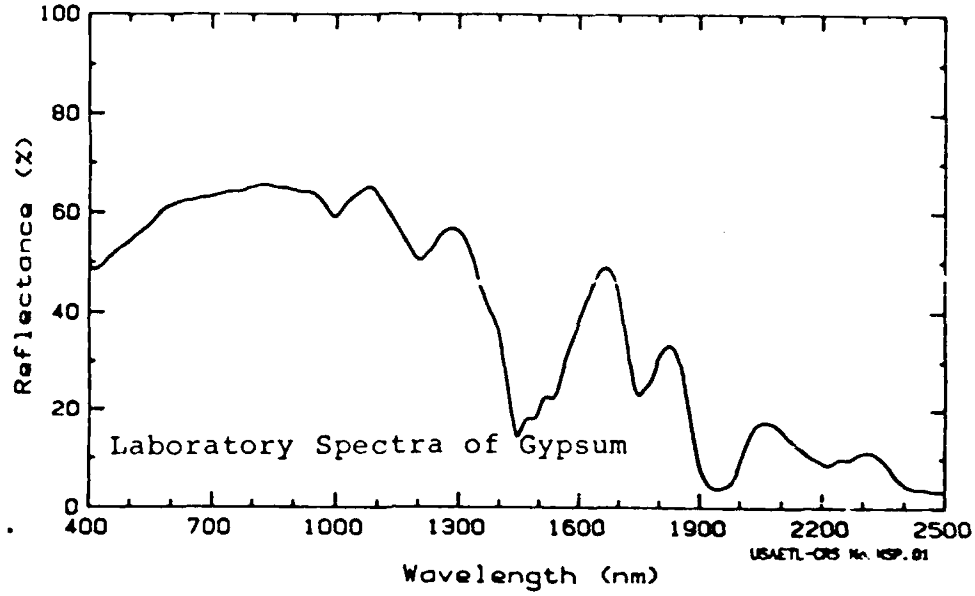

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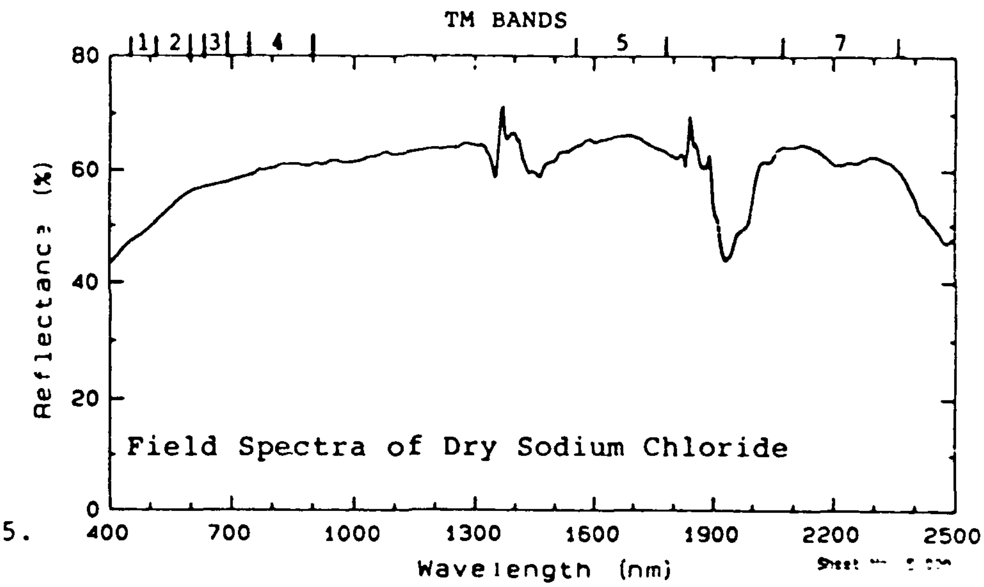

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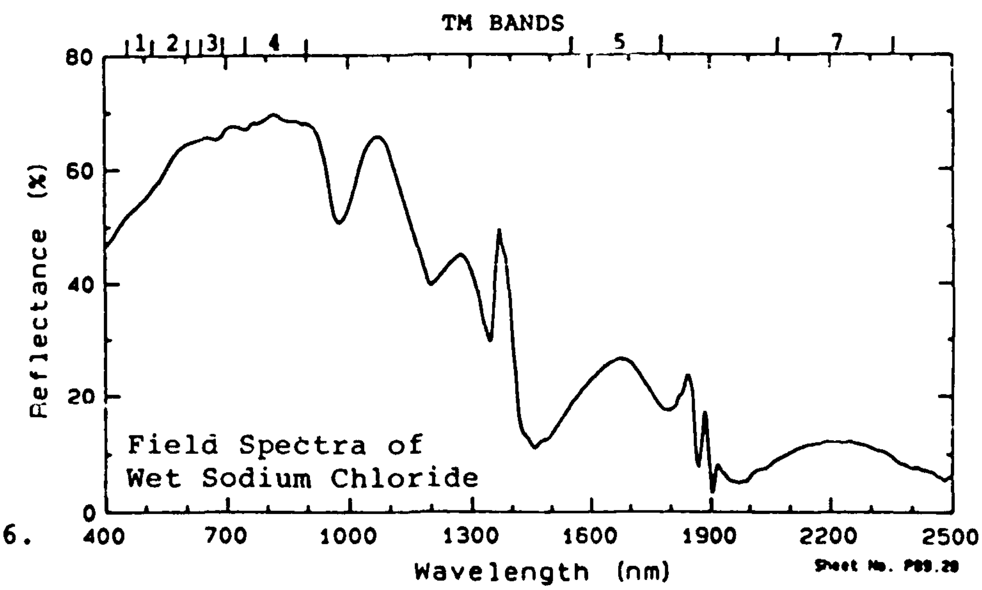

Figure 6.